Amendments to the Specification

In the specification after page 15, line 2, kindly insert the following paragraphs that were previously incorporated by reference:

The present invention provides an improved data communication system which maintains RF communication links between one or more host computers and one or more base transceiver units, each of which may be communicative with many mobile portable transceiver units being moved about a warehouse complex for the collection of data. Specifically, the invention provides a data communication system for collecting and communicating data in the form of RF signals which has a plurality of RF transceivers that store and modify at least one variable operating parameter. From the stored parameter(s), each of transceivers control the operation of transmission and reception. The transceivers also evaluate the effect of the stored parameter based by analyzing each transmission received, and determine whether to make changes in the stored parameter. If changes are needed, the transceivers, modify and store the modified operating parameter and begin operation based thereon.

The operating parameters involve: 1) the size of data segments to be transmitted; 2) the length or frequency of the spreading code used for direct-sequence spread spectrum communication; 3) the hopping rate, coding, and interleaving for frequency-hopping spread spectrum communication; and 4) the type of RF source encoding used.

In addition, the RF transceivers used in the data communication network of the present invention use system-default values to reset the operating parameters if a series of failed communication exchanges occurs, so that communication can be re-established.

It is therefore an object of the invention to provide an adaptive radio communication system which permits the interconnection of one or two host computer devices to a multiplicity of base transceiver units which may include both prior art existing installed units and new generation units capable of spread spectrum radio transmission.

It is a further object of the invention to provide an adaptive RF data communication system

which optimizes communication based on a set of operating parameters.

It is a further object of the invention to provide an adaptive RF data communication system which maintains communication based on a set of operating parameters for optimizing communication, wherein the operating parameters involve: 1) the size of data segments to be transmitted; 2) the length or frequency of the spreading code used for direct-sequence spread spectrum communication; 3) the hopping rate, coding, and interleaving for frequency-hopping spread spectrum communication; and 4) the type of RF source encoding to be used.

It is a further object of the invention to provide a radio communication system network controller which via a communication exchange optimizes a set of operating parameters, yet returns the parameters to their previous or system-default values upon failed communication.

In the specification at the end of page 43, kindly insert the following paragraphs that were previously incorporated by reference:

Multipath Fading and Data Packet Size Parameters.

In a preferred embodiment, the data (or messages) to be sent through the RF communication link is segmented into a plurality of DATA packets and is then transmitted. Upon receipt, the DATA packets are reassembled for use or storage. Data segmentation on the RF link provides better communication channel efficiency by reducing the amount of data loss in the network. For example, because collisions between transmissions on an RF link cannot be completely avoided, sending the data in small segments results in an overall decrease in data loss in the network, i.e., only the small segments which collide have to be re-sent.

Similarly, choosing smaller data packets for transmission also reduces the amount of data loss by reducing the inherent effects of perturbations and fluctuations found in RF communication links. In particular, RF signals are inherently subject to what is termed "multi-path fading". A signal received by a receiver is a composite of all signals that have reached that receiver by taking all available paths from the transmitter. The received signal is therefore often referred to as a "composite signal" which has a power envelope equal to the vector sum of the individual components of the multi-path signals received. If the signals making up the composite signal are of amplitudes that add "out of phase", the desired data signal decreases in amplitude. If the signal amplitudes are approximately equal, an effective null (no detectable signal at the receiver) results. This condition is termed "fading".

An data communication system using segmentation can be found in a pending application of Steven E. Koenck, et al., U.S. Ser. No. 07/305,302 filed Jan. 31, 1989 (Attorney Docket Nos. DN36649; 91 P 422), which is incorporated herein by reference in its entirety. Specific reference is made to Appendix A thereof.

Normally changes in the propagation environment occur relatively slowly, i.e., over periods of time ranging from several tenths (1/10's) of seconds to several seconds. However, in a mobile RF

environment, receivers (or the corresponding transmitters) often travel over some distance in the course of receiving a message. Because the signal energy at each receiver is determined by the paths that the signal components take to reach that receiver, the relative motion between the receiver and the transmitter causes the receiver to experience rapid fluctuations in signal energy. Such rapid fluctuations can result in the loss of data if the amplitude of the received signal falls below the sensitivity of the receiver.

Over small distances, the signal components that determine the composite signal are well correlated, i.e., there is a small probability that a significant change in the signal power envelope will occur over the distance. If a transmission of a data packet can be initiated and completed before the relative movement between the receiver and transmitter exceeds the "small distance", data loss to fading is unlikely to occur. The maximum "small distance" wherein a high degree of correlation exists is referred to hereafter as the "correlation distance".

As expressed in wavelengths of the carrier frequency, the correlation distance is one half (1/2) of the wavelength, while a more conservative value is one quarter (1/4) of the wavelength. Taking this correlation distance into consideration, the size of the data packet for segmentation purposes can be calculated. For example, at 915 MHz (a preferred RF transmission frequency), a quarter wavelength is about 8.2 centimeters. A mobile radio moving at ten (10) miles per hour, or 447 centimeters per second, travels the quarter wavelength in about 18.3 milliseconds. In such an environment, as long as the segment packet size remains well under 18.3 milliseconds, significant signal fluctuations during the duration of a packet transmission is unlikely. In such an preferred embodiment, five (5) millisecond data packet segments are chosen which provides a quasi-static multipath communication environment.

The faster the relative movement between a transmitter and a receiver the greater the effect of fading, and, therefore, the smaller the data segment should be. Similarly, if the relative movement is slower, the data segment can be larger.

Slower fading effects which might be experienced between stationary transceivers in an office building due to the movement of people, mail carts, and the like. In a typical application of

the present invention, the RF transceiver of a mobile unit may be secured with a bar-code scanner such as a deflected laser beam bar-code scanner or an instant CCD bar-code scanner. In such an example, the bar code data could be transmitted to the base station as the RF transceiver and a scanner device were being jointly transported by a vehicle (e.g. a forklift truck) to another site, or the RF transceiver and a scanner, e.g. as a unitary hand-held device, could be carried by the operator to another site as the bar code data was being transmitted to the base station. In such situations, fading is more pronounced.

If fading does not pose a problem on a given network, the overhead associated with segmentation, hand-shaking and reconstruction may not be justifiable. However, where fading exists, such overhead may be required.

In many communication environments, the degree of fading effects varies dramatically both from time to time and from installation to installation. In the preferred embodiment, transmitters and receivers communicate using an optimal data segment size parameter by adapting the size to conform to the communication environment of the network at any given time. For example, if a receiver detects repeated faulty transmissions, the data segment size parameter might be incrementally reduced (under the assumption that fading caused the faults) until the data throughput reaches an optimal level. Similarly, the size of the data segment can be reduced based on a measured indication of the degree of fading in the network.

One example of a receiver making such a measurement of fading can be found in the abandoned patent application of Ronald L. Mahany, U.S. Ser. No. 07/485,313, filed Feb. 26, 1990, which is incorporated herein by reference. Specifically, in that reference, a received signal strength indicator (RSSI) circuit is found in the receiver. The RSSI circuit samples the signal strength of a transmission. If the signal strength samples are evaluated in sequence and the trend analyzed, the degree of fading can be measured. If the signal strength samples decrease in value, it is likely that fading is present in the network. However, just because fading exists does not require segmentation. Only if fading causes the signal strength to drop below the level of the receiver's sensitivity is segmentation required.

A fixed threshold value that is located a safe margain above the receiver's sensitivity is used to determine whether to change the data segment size. If a trend in signal strength shows values falling below the threshold, the data segment size is decreased. If the threshold level is never reached, the segment size might be increased. In addition, the trend associated with a group of signal strength samples can be used to predict the optimal data packet size -- the intersection of the signal strength samples with the threshold defines a segment length that, with a safe margain, can be used effectively used with the current degree of fading.

After receiving a data segment, the receiver sends to the transmitter indications regarding: 1) whether the data segment was received without fault; and 2) what the new optimal segment size should be. The transmitter responds by adjusting the data segment size and then sending the next segment. As can be appreciated, the data segments are adapted based on the previous transmission. Instead of adjusting on the basis of the reception of a single data segment (the previous transmission), other techniques for adjustment are contemplated. For example, the transmitter may also utilize a threshold window (or weighted averaging), inside of which the segment size will not be changed. Only if the requested change by the receiver falls outside of the threshold window will the segment size change. Similarly, the receiver might also utilize such a window -- only requesting a change when the newly forecasted, optimal segment size falls outside of the window.

Direct-Sequence Spread Spectrum Parameters.

As described above, the network controller provides an interface to both the older generation UHF radio transceivers and newer generation spread spectrum transceivers. A spread spectrum broadcasting system uses a sequential pseudo-noise signal to spread a signal that is in a relatively narrow band over a wider range of frequencies. It is the subject of standards issued by the Federal Communications Commission (FCC) that provide usable spectrum at low power levels for communication in limited areas such as warehouses, office buildings, and the like. The use of spread-spectrum techniques minimizes interference with others using the same channels in the spectrum.

A transmitter using direct-sequence spread spectrum transmission uses a spreading-code of a higher frequency than that of the data rate to encode the data to be sent. This higher frequency is achieved by increasing the chip clock rate (wherein each chip constitutes an element of the spreading-code). Using the same spreading code, the receiver decodes the received signal while ignoring minor faults which occurred in transmission, providing noise immunity and multipath signal rejection. The frequency and length of the spreading-code can be varied to offer more or less multipath signal rejection or noise immunity. Although it may result in improved communication, increasing the frequency or length of the spreading-code requires additional overhead which may not be justifiable unless necessary.

Frequency-Hopping Spread Spectrum Parameters.

Frequency-hopping is the switching of transmission frequencies according to a sequence that is fixed or pseudo-random and that is available to both the transmitter and receiver. Adaptation to the communication environment via an exchange in frequency-hopping operating parameters is possible, for example, via selective control of the hopping rate or through the use of coding or interleaving. The greater the degree of frequency selectivity of the fading envelope (i.e., when fading is significant only over a portion of the spectrum of hopping frequencies), the greater the benefit of such adaptation.

Particularly, a parameter indicating the hopping rate can be varied to minimize the probability that the channel characteristics will detrimentally change during the course of a communication exchange. To vary the hopping rate is to vary the length of a hopping frame. Although multiple data (or message) exchanges per hopping frame is contemplated, the preferred hopping frame consists of a single exchange of data. For example, in a polling environment, the hopping frame might consist of: 1) a base station transmitting a polling packet to a roaming terminal; 2) the roaming terminal transmitting data in response; and 3) the base station responding in turn by transmitting an acknowledge packet. Each hopping frame exchange occurs at a different pseudo-randomly chosen frequency.

For optimization, the hop frame length is adjusted to be as long as possible, while remaining shorter than the coherence time of the channel by some safety margin. Although such adjustment does not eliminate the effects of fading, it increases the probability that the characteristics of the channel will remain consistent during each hopping frame. Thus, in the preferred embodiment, if the polling packet transmission is successfully received, the probability of successful receipt of the data (or message) and acknowledge is high.

Another parameter for changing frequency-hopping performance is that of coding. Coding on the channel for error correction purposes can be selectively used whenever the probability of data or message loss due to fading is high. In particular, coding methods which provide burst error correction, e.g., Reed-Solomon coding, can be applied if the hop length is likely to exceed the coherence time of the channel. Such coding methods allow some portion of the data to be lost and reconstructed at the expense of a 30-50% reduction in throughput. The operating parameter for coding indicates whether coding should be used and, if so, the type of coding to be used.

An operating parameter indicating whether interleaving should be used also helps to optimize the communication channel. Interleaving involves breaking down the data into segments which are redundantly transmitted in different hopping frames. For example, in a three segment exchange, the first and second segments are sequentially combined and sent during a first hopping frame. In a subsequent hopping frame, the second and third segments are combined and sent. Finally, the third and first segments are sequentially combined and transmitted in a third hopping frame. The receiving transceiver compares each segment received with the redundantly received segment to verify that the transmission was successful. If errors are detected, further transmissions must be made until verification is achieved. Once achieved, the transceiver reconstructs the data from the segments.

Other methods of interleaving are also contemplated. For example, a simpler form of interleaving would be to sequentially send the data twice without segmentation on two different frequencies (i.e., on two successive hops).

As can be appreciated, interleaving provides for a redundancy check but at the expense of

data or message throughput. The interleaving parameter determines whether interleaving is to be used and, if so, the specific method of interleaving.

In addition, any combination of the above frequency-hopping parameters might interact to define an overall operating configuration, different from what might be expected from the sum of the individual operating parameters. For example, selecting interleaving and coding, through their respective parameters, might result in a more complex communication scheme which combines segmentation and error correction in some alternate fashion.

Source Encoding Parameters (For Narrowband Applications).

In the United States, data communication equipment operating in the ultra-high frequency (UHF) range under conditions of frequency modulation (FM) is subject to the following limitations.

(1) The occupied band width is sixteen kilohertz maximum with five kilohertz maximum frequency deviation.

(2) The channel spacing is 25 kilohertz. This requires the use of highly selected filtering in the receiver to reduce the potential for interference from nearby radio equipment operating on adjacent channels.

(3) The maximum output power is generally in the range of ten to three hundred watts. For localized operation in a fixed location, however, transmitter power output may be limited to two watts maximum, and limitations may be placed on antenna height as well. These restrictions are intended to limit system range so as to allow efficient re-use of frequencies.

For non-return to zero (NRZ) data modulation, the highest modulating frequency is equal to one half the data rate in baud. Maximum deviation of five kilohertz may be utilized for a highest modulation frequency which is less than three kilohertz, but lower deviations are generally required for higher modulation frequencies. Thus, at a data rate of ten thousand baud, and an occupied bandwidth of sixteen kilohertz, the peak FM deviation which can be utilized for NRZ data may be three kilohertz or less.

Considerations of cost versus performance tradeoffs are the major reason for the selection of

the frequency modulation approach used in the system. The approach utilizes shaped non-return-to-zero (NRZ) data for bandwidth efficiency and non-coherent demodulation using a limiter-discriminator detector for reasonable performance at weak RF signal levels. However, the channel bandwidth constraints limit the maximum data "high" data rate that can be utilized for transmitting NRZ coded data. Significant improvements in system throughput potential can be realized within the allotted bandwidth by extending the concept of adaptively selecting data rate to include switching between source encoding methods. The preferred approach is to continue to use NRZ coding for the lower system data rate and substitute partial response (PR) encoding for the higher rate. The throughput improvements of a NRZ/PR scheme over an NRZ/NRZ implementation are obtained at the expense of additional complexity in the baseband processing circuitry. An example of a transceiver using such an approach can be found in the previously incorporated patent application of Ronald L. Mahany, U.S. Ser. No. 07/485,313, filed Feb. 26, 1990.

Partial response encoding methods are line coding techniques which allow a potential doubling of the data rate over NRZ encoding using the same baseband bandwidth. Examples of PR encoding methods include duobinary and modified duobinary encoding. Bandwidth efficiency is improved by converting binary data into three level, or pseudo-ternary signals. Because the receiver decision circuitry must distinguish between three instead of two levels, there is a signal to noise (range) penalty for using PR encoding. In an adaptive baud rate switching system, the effects of this degradation are eliminated by appropriate selection of the baud rate switching threshold.

Since PR encoding offers a doubling of the data rate of NRZ encoded data in the same bandwidth, one possible implementation of a NRZ/PR baud rate switching system would be a 4800/9600 bit/sec system in which the low-pass filter bandwidth is not switched. This might be desirable for example if complex low-pass filters constructed of discrete components had to be used. Use of a single filter could reduce circuit costs and printed circuit board area requirements. This approach might also be desirable if the channel bandwidth were reduced below what is currently available.

The preferred implementation with the bandwidth available is to use PR encoding to

increase the high data rate well beyond the 9600 bit/sec implementation previously described. An approach using 4800 bit/sec NRZ encoded data for the low rate thereby providing high reliability and backward compatibility with existing products, and 16K bit/sec PR encoded transmission for the high rate may be utilized. The PR encoding technique is a hybrid form similar to duobinary and several of its variants which has been devised to aid decoding, minimize the increase in hardware complexity, and provide similar performance characteristics to that of the previously described 4800/9600 bit/sec implementation. While PR encoding could potentially provide a high data rate of up to 20K bit/sec in the available channel bandwidth, 16K bit/sec is preferable because of the practical constraints imposed by oscillator temperature stability and the distortion characteristics of IF bandpass filters.

Exchanging Parameters.

All of the above referenced parameters must be maintained in local memory at both the transmitter and the receiver so that successful communication can occur. To change the communication environment by changing an operating parameter requires both synchronization between the transceivers and a method for recovering in case synchronization fails.

In a preferred embodiment, if a transceiver receiving a transmission (hereinafter referred to as the "destination") determines that an operating parameter needs to be changed, it must transmit a request for change to the transceiver sending the transmission (hereinafter the "source"). If received, the source may send an first acknowledge to the destination based on the current operating parameter. Thereafter, the source modifies its currently stored operating parameter, stores the modification, and awaits a transmission from the destination based on the newly stored operating parameter. The source may also send a "no acknowledge" message, rejecting the requested modification.

If the first acknowledge message is received, the destination modifies its currently stored operating parameter, stores the modification, sends a verification message based on the newly stored operating parameter, and awaits a second acknowledge message from the source. If the destination

does not receive the first acknowledge, the destination sends the request again. If after several attempts the first acknowledge is not received, the destination modifies the currently stored parameter, stores the modification as the new operating parameter, and, based on the new parameter, transmits a request for acknowledge. If the source has already made the operating parameter modification (i.e., the destination did not properly receive the first acknowledge message), the destination receives the request based on the new parameters and responds with a second acknowledge. After the second acknowledge is received, communication between the source and destination based on the newly stored operating parameter begins.

If the destination does not receive either the first or the second acknowledge messages from the source after repeated requests, the destination replaces the current operating parameter with a factory preset system-default (which is also loaded upon power-up). Thereafter, using the system-default, the destination transmits repeated requests for acknowledge until receiving a response from the source. The system-default parameters preferably define the most robust configuration for communication.

If after a time-out period the second request for acknowledge based on the newly stored operating parameters is not received, the source restores the previously modified operating parameters and listens for a request for acknowledge. If after a further time-out period a request for acknowledge is not received, the source replaces the current operating parameter with the factory preset system-default (which is the same as that stored in the destination, and which is also loaded upon power-up). Thereafter, using the common system-default, the source listens for an acknowledge request from the destination. Once received, communication is re-established.

Other synchronization and recovery methods are also contemplated. For example, instead of acknowledge requests originating solely from the destination, the source might also participate in such requests. Similarly, although polling is the preferred protocol for carrying out the communication exchanges described above, carrier-sense multiple-access (CSMA) or busy tone protocols might also be used.

In addition, Appendix F provides a list of the program modules which are found in

Appendix G. These modules comprise another exemplary computer program listing of the source code ("C" programming language) used by the network controllers and intelligent base transceivers of the present invention. Note that the term "AMX" found in Appendices F and G refers to the operating system software used. "AMX" is a multitasking operating system from KADAK Products, Ltd., Vancouver, B.C., Canada.

As is evident from the description that is provided above, the implementation of the present invention can vary greatly depending upon the desired goal of the user. However, the scope of the present invention is intended to cover all variations and substitutions which are and which may become apparent from the illustrative embodiment of the present invention that is provided above, and the scope of the invention should be extended to the claimed invention and its equivalents. It is to be understood that many variations and modifications may be effected without departing from the scope of the present disclosure.